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Management of *Eucalyptus* plantations influences small mammal density: Evidence from Southern Europe

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Forestry plantations, and particularly those of exotic *Eucalyptus*, are important man-made systems in Europe, and especially in Portugal, where these represent now the largest fraction of forested areas. *Eucalyptus* plantations may have impacts on vertebrate communities in Europe; however, these have been seldom assessed. Although it is commonly understood that such impacts are contingent on type, shape size and spatial arrangement of landscape elements. Thus, in this study we tested the effects of *Eucalyptus* plantations and the surrounding native semi-natural ecosystems on small mammal density in Central Portugal. We used a Spatially Explicit Capture-Recapture (SECR) model to estimate density, and Generalized Linear (Mixed) Models (GLM/GLMM) to test the effects of habitat type and understory composition and structure on mammal density. Our results showed no significant effect of *Eucalyptus* plantations on density of small mammals, but the presence of a developed understory was positively related to density, likely because it provides food and refuge resources. At the species level, we only found a negative effect of *Eucalyptus* plantations on wood mouse (*Apodemus sylvaticus*) density, most likely because these forests do not provide its preferred food resources (e.g. acorns); this hypothesis was further supported by the positive effect of proximity to ecotone habitat that likely resulted in increased food provisioning. These results highlight that the impact of *Eucalyptus* plantations on small mammals is mostly species-dependent and determined by management and the location of native habitat patches.

1. Introduction

Human-shaped ecosystems are dominant in many parts of the world (Martin et al., 2014) and are expected to continue expanding alongside with the projected growing global population. These ecosystems represent a gradient ranging from relatively low use to intensive use, often with irreversible change (Kehoe et al., 2015). The human-driven alteration of ecosystems results in changes in composition and structure of natural communities, likely modifying underlying ecological processes (Foley et al., 2005). The type and intensity of use and its management impacts flora and fauna differently (Flynn et al., 2009). For example, conversion of native ecosystems for vast wood production monoculture plantations threatens the persistence of the native biological communities (e.g. Laiolo et al., 2003), by limiting dispersal and gene flow (e.g., Banks et al., 2005), reducing food and shelter availability (e.g., Rishworth et al., 1995; Parker, 1986), and changing microclimate, nutrient and water conditions (e.g., Liechty et al., 1992). Nonetheless, such human-shaped ecosystems can also be neutral or beneficial in their impacts to the natural communities. For example, Martin et al. (2014) showed that Neotropical *Eucalyptus* plantations had no influence on small mammal body condition, showing/suggesting that some species can even nest inside plantations, although other native species were only detected within its limits.

Globally, exotic forest plantations have been expanding in the last decades and cover now >264 million hectares (FAO, 2010). *Eucalyptus* spp. is one of the most important forestry species, occupying >20 million hectares in temperate and tropical regions (Forrester and Smith, 2012). This increase in *Eucalyptus* production

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areas is associated with its high yield, short production cycle, diverse uses of its wood (e.g. fiber, sawtimber, construction, etc.), high capacity to withstand variable climatic conditions, and ability to be manipulated to produce hybrids and clones with higher wood quality and resilience to regional climates (Campinhos, 1999). In Portugal, *Eucalyptus* spp. are already the most important forestry species, covering 26% of Portuguese forests (ICNF, 2013) that amount to 47% of the *Eucalyptus* production forests in Europe (Iglesias-Trabado et al., 2009). The plantation of exotic *Eucalyptus* have raised several environmental issues associated with the replacement of native ecosystems, namely invasiveness potential, fire risk, unsustainable water use, and production sustainability (Stanturf et al., 2013).

Nonetheless, the impact of *Eucalyptus* plantations on native vertebrate communities is variable and contingent on taxa and landscape context (i.e. type, shape size and spatial arrangement of other landscape components, such as native patches). For example, *Eucalyptus* plantations have shown limited impact on amphibians in the Iberian Peninsula (i.e., constraining the occurrence of some species, but promoting other and not affecting many; Cruz et al., 2015), while in the Brazilian state of São Paulo *Eucalyptus* forests are inhabited by half of the bird species found in native vegetation (Penteado et al., 2016). Further, the presence of native vegetation strips ("cerrado") within *Eucalyptus* plantations was shown to enhance insect diversity to a value very close to that measured in "cerrado" reserves of Mina Gerais state, Brazil (Zanuncio et al., 1998). The use of *Eucalyptus* plantations by vertebrates may also vary with plantation age. For instance, generalist small mammal species are early colonizers of *Eucalyptus* plantations while more specialist species only appear in latter management stages (e.g., Martin et al., 2012). Larger mammals, on the other hand, avoid pre-harvesting stands at latter management stages (Timo et al., 2014).

The negative impacts of *Eucalyptus* plantations may be counteracted by management. For example, adequate management of the harvest cycle may enhance the habitat provisioning capacity of *Eucalyptus* plantations for many vertebrates (Verdade et al., 2014). Plantations with remnants of natural vegetation tend to have higher species richness than monocultures (e.g. Zanuncio et al., 1998), as natural vegetation likely serve as a refuge/cover/shade (Hartley, 2002) being also source of colonizers of several species (Vidal et al., 2016). Several studies have shown that understory vegetation is one of the most influential factors for biodiversity in forestry plantations (e.g. Cerda et al., 2015; López and Moro, 1997), with *Eucalyptus* plantations with understory of native shrubs hosting as much as 40% of the small mammals found in primary forests (Barlow et al., 2007). Some authors suggest that to provide habitat for native wildlife (and promote a diversified understory layer) it is possible to thin plantations earlier, to exclude some areas of herbicide application or to reduce clearcutting actions (Hartley, 2002). It is therefore important to understand which is the *Eucalyptus* plantation structure and associated management regime that best enhance vertebrate population densities, a necessary step towards conservation and a sustainable landscape (Sinclair et al., 2006).

In this study, we compared small mammal density in an *Eucalyptus* plantation and in the surrounding native semi-natural ecosystem, testing the effects of habitat type and understory composition and structure. We expected lower small mammal density in *Eucalyptus* stands when compared to native ecosystems because *Eucalyptus* may provide fewer resources (e.g. Majer and Recher, 1999), i.e. lower food availability (Stallings, 1990; Stephens and Wagner, 2007), and/or less refuges (Stallings, 1990).

2. Materials and methods

2.1. Study area

This study was carried out at "Companhia das Lezírias, S.A." a state farmstead located 40 km northeast of Lisbon, Portugal (38°4 9′22.34″N, 8°52′3.24″W; Fig. 1). The region is characterized by hot dry summers and cold rainy winters typical of Mediterranean climates, with an average annual temperature of 16.3 °C and 700 mm rainfall (Gonçalves et al., 2012).

Companhia das Lezírias, S.A. (hereafter termed CL) is the largest agro-forestry farmstead in Portugal, including an area of 11,000 ha (Charneca farmstead) where main activities are cattle breeding, forestry and agriculture. The main land use (6725 ha) is the semi-natural forest of the native cork oak (*Quercus suber*), called *montado*, where agroforestry productions co-exist with high biodiversity (Pinto-Correia et al., 2011), mammals included (Gonçalves et al., 2012). Other forestry systems are also present in the farmstead, such as pinewoods (maritime pine *Pinus pinaster* and umbrella pine *Pinus pinea* - 1500 ha) and *Eucalyptus* plantations (*Eucalyptus globulus* - 476 ha). Forestry stands are interspersed with agriculture fields, including rice fields (630 ha), pastures (460 ha), olive yards (59 ha), and vineyards (140 ha) (Companhia das Lezírias, 2010). The present study was conducted in two of CL's forestry systems: exotic *Eucalyptus* plantations and native cork oak *montado*. In each forestry type, a sampling area of 400 ha was defined representing one treatment (*Eucalyptus*) and one control (*montado*) site.

2.2. Small mammal trapping and handling

Small mammal trapping was conducted in the fall (October and November 2014) and repeated again in the spring (March and April 2015) to represent two life-cycle periods: pre and post-reproduction, respectively. The two sampling areas (*Eucalyptus* plantation and cork oak *montado*) were selected in close proximity to ensure similarity in physiographic conditions, but sufficiently far apart to prevent animals to move between the two areas (ca. 9 km). In each area, we established 9 sampling points, forming a 3 by 3 grid, with points spaced 1 km from each other (Fig. 1). On each sampling point we defined a smaller 40 × 40 m grid, with 25 trapping points spaced 10 m apart, covering a total area of 1600 m^2. In all 25 trapping points we set three different live traps, all located in a circle with 1 m radius: two Sherman traps of distinct sizes (38 × 10 × 12 cm and 23 × 8 × 9 cm) and one pitfall trap (plastic bucket; 14 × 14 × 17 cm). The combined use of three types of traps aimed to maximize multi-species trapping efficiency (Gurnell and Flowerdew, 2006), since species with very distinct morphological and ecological characteristics are present in the area (Gonçalves et al., 2012).

Sherman traps were placed at the ground level and covered with vegetation to avoid direct sun exposure. These traps were baited with a mixture of canned sardine in oil and oatmeal, and cotton was added to provide nest material to minimize possible effects of small mammal stress and hypothermia (Gurnell and Flowerdew, 2006). Pitfall traps were buried, and buckets had holes in the bottom to allow drainage of rainwater, and contained a piece of styrofoam to prevent animals from drowning. The traps were placed in the field and kept closed for two nights prior to the sampling period to minimize trap avoidance. After the acclimation period, traps were set active for four consecutive nights and checked every morning. Bait and bedding were checked at each trap visit.

Captured animals were marked individually by fur clipping at predefined areas of the animal's body, following the protocol defined by Gurnell and Flowerdew (2006). These marks allowed